EMITTANCE MEASUREMENT USING X-RAY BEAM PROFILE MONITOR AT KEK-ATF

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Abstract

The X-ray profile monitor (XPM) is used for the beam size measurement in the KEK-ATF damping ring(ATF-DR) at all times. The XPM consists of a crystal monochromator, two Fresnel zone plates(FZPs) and X-ray CCD camera. Two FZPs make the imaging optics. The design resolution of the selected wavelength 3.8nm is less than 1μm, which is sufficiently small for the emittance measurement of the ATF-DR. However, the measured results at the early stage were affected by the mechanical vibration. This paper describes the improvement of the resolution and the measurement results.

INTRODUCTION

The damping ring(DR) of the KEK-ATF has been designed to produce extremely low emittance beam for future accelerator technologies, especially focus on the International Linear collider(ILC).[1][2] The beam energy is 1.3GeV. The design horizontal emittance(ε_x), we call "emittance" as "un-normalized emittance", at a zero current is 1.1 x 10^{-11}m. The vertical emittance(ε_y) is 1×10^{-11}m when assuming 1% coupling. The expected beam size for the vertical is 5.5μm, at the location of the beam size monitor. The beta function at the location is 3m for the vertical. The beam size monitor needs to have enough resolution for 5.5μm measurement. The recent tuning effort of the DR is aiming to reduce the vertical emittance less than 1×10^{-11}m. In this case, the vertical beam size reduces to 4μm($\varepsilon_y=5\times10^{-12}$m) or 3μm($\varepsilon_y=3\times10^{-12}$m).

The X-ray profile monitor(XPM) was constructed by Tokyo University group[3][4] to measure the beam size in the DR. The XPM is a long-distance X-ray microscope, which consists of a crystal monochromator, two Fresnel zone plates(FZPs) and an X-ray CCD camera. The X-ray of the synchrotron radiation from the bending magnet is monochromatized by a crystal monochromator with the wavelength of 0.38nm(3.235keV). The two FZPs constitute imaging optics and the magnification ratio from the source to the CCD camera is 20. The estimated resolution of the XPM is less than 1μm, which is enough to measure the vertical DR emittance. The detail of the design parameter and the specification of the FZPs are described in [3].

At the beginning of the system commissioning, the measured beam size could not be less than 6μm in vertical, which correspond to 1.2 x 10^{-11}m of the vertical emittance. However, the emittance evaluated from other beam size monitors, a laser wire profile monitor(LW)[5] and a SR interferometer(SRI)[6] was less than 1.0 x 10^{-11}m. We investigated the reason of the discrepancy among the XPM, the LW and the SRI. We found that the mechanical vibration of the crystal monochromator deteriorated the minimum spot size. The minimum beam size 4μm was measured after reduced the mechanical vibration.

A standalone video analyser was used, which didn't have an interface to connect the accelerator control system. To synchronize the beam profile data with the other DR parameters, an online video analysis system was constructed. The new video analysis system can be controlled from the accelerator control system and can monitor the beam profile synchronized with the other machine parameters.

SYSTEM DESCRIPTION

The layout of the XPM is shown in Figure 1. The synchrotron radiation (SR) from the bending magnet(BH1R.27) located just before the long straight section is used for the XPM. The SR parameters are summarized in Table 1.

Table 1: Parameters of the SR of BH1R.27

Beam energy	1.3 GeV
Magnetic field of BH1R.27	0.75 T
Bending radius	5.4m
Critical energy of the SR	0.816 keV

The SR is monochromatized by a Si monochromater with crystal lattice plane Si(220), Bragg angle 86.35° and spectral resolution 5.6 x 10^{-5} for the wavelength 0.38nm(3.235keV). The two FZPs (Condenser Zone Plate : CZP, Micro Zone Plate : MZP) make the imaging optics. The CZP and the MZP have 0.91m and 24.9mm of the focal length, respectively. The magnification ratio of the CZP and the MZP are 0.1 and 200, respectively.

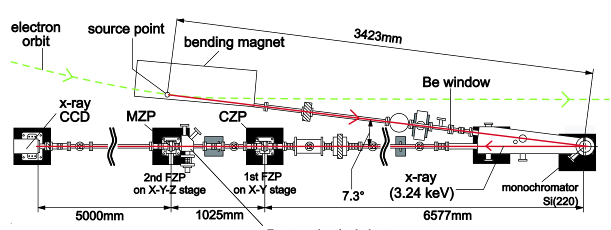

Figure 1: Layout of the XPM.

The image of the source point is magnified 20 times on the X-ray CCD. The X-ray CCD camera (HAMAMATSU C4742-98-KWD) is a direct incident type with a

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back-thinned illuminated CCD, which has high QE. The pixel size is 24μm x 24 μm and the pixels are 512 x 512. The camera head is cooled to -50 °C and keep a high vacuum condition for the low thermal noise. The minimum exposure time is 20ms and the frame rate is 6 frame/sec. The CCD is a full-frame transfer type and the CCD needs a mechanical shutter to cut off the X-ray irradiation during the readout of the charge on the CCD.

NEW VIDEO ANALYZER

We fabricated the in-house made software based on the linux library. The new video analyzer software has a network interface, which can be controlled from the accelerator control software. The acquired data (the profile, the beam size, the intensity, etc.) can be saved to the database of the accelerator control with the other accelerator parameters. The acquisition speed is more than 3Hz. The normal operation of the ATF-DR is 1.5Hz. It is enough to acquire all of the shot of the beam. Figure 2 shows the example of the XPM image by the software. The position control of the XPM image is included in the software. The mover of the MZP can control from this window.

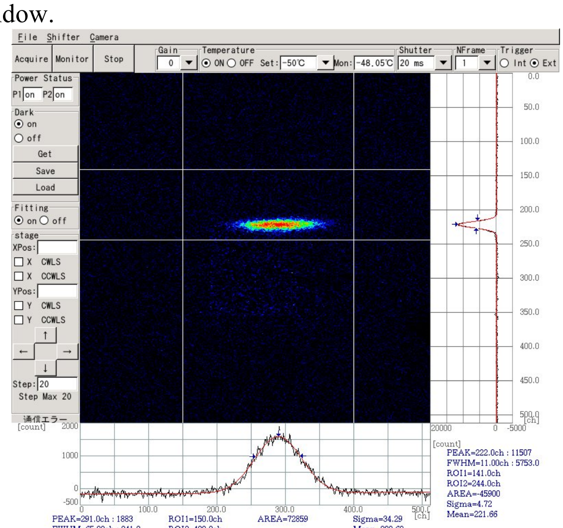

Figure 2: Example of the XPM image using the new software.

By using this software, the all of the beam profile data could store to the database of the accelerator control system synchronized with the other parameters. This data can be used for the beam tuning to minimize the vertical emittance as a real time monitor. The trend graph of the XPM is shown in Figure 3. The DR stored current measured with the DCCT(blue line) is plotted with the XPM data (the horizontal beam size, the horizontal beam position, the vertical beam size and the vertical beam position). The current dependence of the horizontal beam size can be seen in this graph.

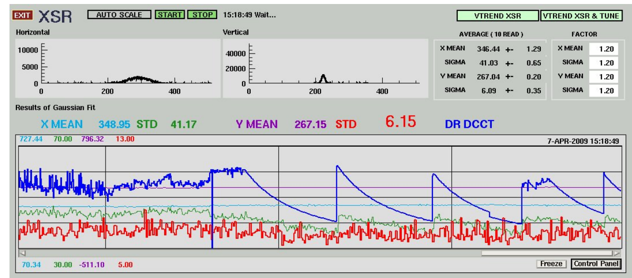

Figure 3: Trend graph of the XPM –DCCT (blue line), the horizontal beam size(green line), the horizontal position(light blue line), the vertical beam size(red line) and the vertical position(purple line) are plotted in the graph.

IMPROVEMENT OF THE BEAM SIZE MEASUREMENT

Figure 4 shows the vertical beam size measurement in 2005. In the case of the ATF-DR, the beam size is a function of the bunch current due to the intra-beam scattering. The lines show the calculation. The measured beam size was around 6μm and was not so clear the current dependence. It seems the measured beam size was somewhat limited. The oscillation of the vertical beam position was observed on the CCD using 1ms fast mechanical shutter [4]. The frequency was 100Hz. It seemed the vertical profile was smeared by the oscillation during the exposure time.

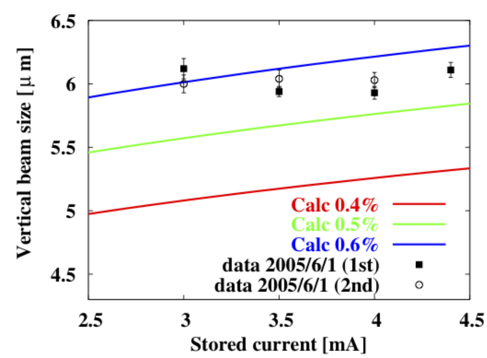

Figure 4: Vertical beam size measurement in 2005.

We measured the mechanical vibration of each component. The spectrum of the mechanical vibration in vertical direction at the Si monochromater is shown in Figure 5. The red line shows the Si monochromater and the blue line shows the floor just beneath of the Si monochromater. The Si monochromater had a large peak at 100Hz. We tried to find out the source of the vibration. Finally, we found two blowers to cool the waveguide of the RF system caused the vibration. The RF cavities are located 2m down stream of the XPM and the two blowers sit on the floor just below of the cavities. We moved the two blowers to 7m downstream of the XPM and inserted cushions between the blower and the floor. The exhausts of the blower are connected using long flexible ducts.

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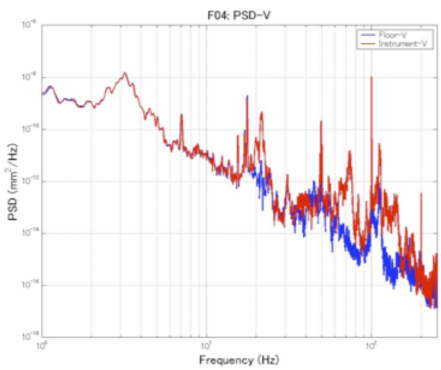

Figure 5: Spectrum of the mechanical vibration in vertical direction at the Si monochromater.

The vertical beam size measurement after treated the mechanical vibration is shown in Figure 6. The measured vertical beam size was 5+/-0.3μm at the bunch charge of 0.8 x 10^{10} electrons(3.0mA). The current dependence can be seen in the plot, which means that the XPM does not have limitted the minimum beam size. The measured minimum beam size was 4μm at this time.

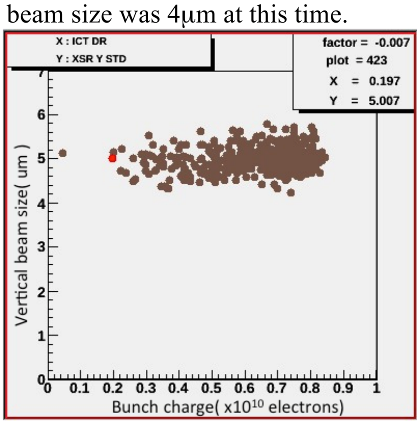

Figure 6: Vertical beam size measurement in 2012.

Emittance Measurement

The beta function at the quadrupole magnet is measured from the strength dependence of the betatron tune. The beta function at the source point of the XPM is estimated from the fitting of the beta functions among the quadrupole magnets. Five magnets are used for the fitting.

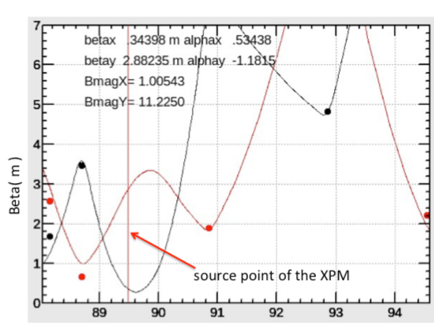

Figure 7: Fitting of the beta function near the source point of the XPM.

Figure 7 shows the fitting curve of the beta function. The source point of the XPM is as the location of the red straight line. The contribution of the dispersion function in vertical direction is negligibly small. The estimated vertical emittance at the bunch charge of 0.8 x 10^{10} electrons is 8.6 x 10^{-12} m.

SUMMARY

The XPM is a important monitor to measure the emittance of the ATF-DR. The measurable minimum beam size was limited by the mechanical vibration of the Si monochromater. The mechanical vibration was come from the vibration of the blower to cool the waveguide of the RF system. We succeeded to improve the measurable minimum beam size by removing the vibration source. The measured vertical emittance was 8.6 x 10^{-12}m.

The online data acquisition is required for monitoring the accelerator conditions. We fabricated the video analyser software for the online analysis of the beam profile and the other accelerator parameters. All of the beam profile data could be stored to the database of the accelerator control system synchronized with the other parameters.

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